ADJACENT CHANNEL INTERFERENCE CRITERIA FOR AERONAUTICAL TELEMETRY OPERATIONS WITH THE TACTICAL TARGETING NETWORK TECHNOLOGY SYSTEM

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ABSTRACT

This paper will provide recommended channel spacing requirements when the Tactical Targeting Network Technology (TTNT) System is utilized in conjunction with airborne telemetry systems at airborne test ranges. The recommendation will be in the form of an equation similar in form to the adjacent channel interference (ACI) equation currently in the Telemetry Standard IRIG-106. Test results will be presented to support this recommendation.

KEY WORDS

Tactical Targeting Network Technology (TTNT), adjacent channel interference (ACI), carrier to interferer (C/I), telemetry

INTRODUCTION

The Tactical Targeting Network Technology (TTNT) system has been tested using early validation units and has matured to the point of Phase 3 hardware. This hardware requires over-the-air range testing time at Test Ranges within the Edwards AFB/China Lake/Pt. Mugu test complex. Because of the approved bands of operation and power levels in which the system operates, interference with aeronautical mobile telemetry (AMT) serial streaming telemetry signals is a distinct possibility. This paper briefly explains the TTNT system and its waveform, then describes the test set-up required to perform the ACI testing between TTNT and telemetry signals. The test results are presented and a preliminary channel spacing recommendation is made for the co-existence of TTNT and telemetry signals in a shared band scenario.

TTNT SYSTEM CHARACTERISITCS

TTNT is an Internet Protocol (IP) based dynamic ad hoc network designed to enable the U.S. military to quickly move information to/from multiple platforms. TTNT is intended to support more than 200 users at any given time for secure, jam-resistant transmissions and to allow reception of four or more independent streams simultaneously. Each TTNT node has RF ports for upper and lower antenna connections with either port, or both, transmitting/receiving. Each of the antenna ports transmits at a peak level of 151W (+51.8dBm). The physical layer consists of a single information carrier with Gaussian Minimum Shift Keying (GMSK) modulation while the media access is handled through time division methods. The system frequency hops between a preconfigured set of 16 center frequencies, set prior to testing. (Note: All 16 frequencies do not have to be used.) Figure 1 illustrates the TTNT Phase 3 terminal.

Figure 1 - TTNT Phase 3 Terminal

Of the 16 channels available, 7 lie in the 1755MHz to 1850MHz band (Band 1), 6 lie in the 1435MHz to 1518MHz band (band 2) and 3 lie in the 1350MHz to 1390MHz band (Band 3). Channel spacing of the 16 channels is fixed to a center to center spacing of 13 1/3MHz. It should be noted that AMT users have primary use of Band 2 and are secondary users in Band 1. In other words, AMT and TTNT must co-exist if the TTNT system is flown in aeronautical test ranges.

A spectral plot of two channels of the TTNT system is shown in Figure 2. The spectra presented are typical of all 16 channels.

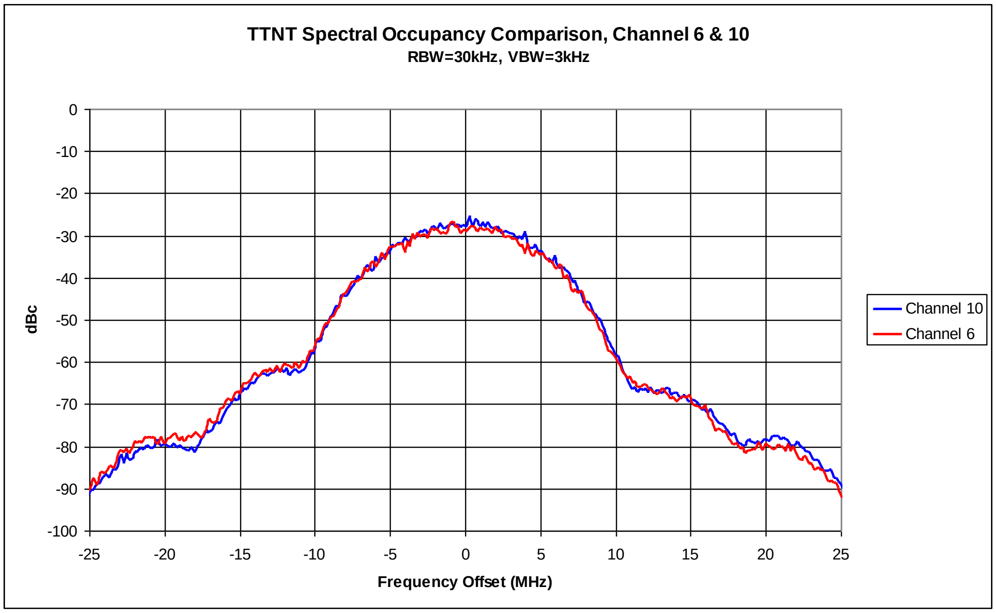

Figure 2 – TTNT Spectrum Comparison

The Ranges use spectral occupancy for determining the amount of bandwidth to be scheduled for flight testing when transmitting telemetry signals. When AMT spectrum availability is low, how close channels can be packed becomes very important. To determine the spectral occupancy, the occupied bandwidth of the TTNT signal is measured. Several bandwidth criteria are used throughout the telemetry community with the most accepted ones being the 99% and 99.9% occupied bandwidth criteria used in IRIG-106. Sometimes individual Ranges determine occupied bandwidth by other criteria such as the -60dBc width point to determine the amount of required "scheduled bandwidth". See Table 1 for the bandwidth values associated with the TTNT waveform.

Spectral Occupancy Criteria	**Width (MHz)**
99.0% OBW	14.3
99.9% OBW	18.5
-60dBc	23

Table 1 – TTNT Spectral Occupancy per Channel

ACI TEST SET-UP

The ACI testing results presented here determine acceptable spacing criteria between telemetry signals and individual channels of the TTNT system. Since the waveform being interfered with is the telemetry signal it will be referred to as the 'victim' signal. The telemetry signals will either be Pulse Code Modulation/Frequency Modulation (PCM/FM) or Shaped Offset Quadrature Phase Keying Telemetry Group version (SOQPSK-TG) per IRIG-106. The interfering signal, (otherwise known as the 'interferer') is the TTNT signal. An acceptable degradation level was assessed in terms of energy per bit to noise power spectral density ratio (Eb/No) for a fixed bit error rate. *A difference of 1dB of required Eb/No to achieve an error rate of $1x10^{-5}$ as the victim is moved closer to the interferer is the threshold interference criteria.* For this testing and to stay consistent with prior work, the interfering signal was assumed to be no larger than 20dB greater in amplitude than the victim. Typically this assumption is for equal power transmitters, in the range of 5-10W (+37 to +40dBm) operating in a near/far geometry (one test article closer than the other in the same ground station antenna beam) . Since the output power of the TTNT terminal is much higher than that of traditional telemetry transmitters (+52dBm), this 20dB amplitude difference assumption will also be used, though it follows that the TTNT terminal can be at a larger slant range (near case) than what was assumed in Law's [4, 5] work. See Table 2 for a summary of the ACI test conditions.

Victim Bit Rate	5/10/20Mbps (SOQPSK) 1/5Mbps (PCM/FM)
Victim Modulation Mode 1	PCM/FM, peak deviation 0.35(bit rate)
Victim Modulation Mode 2	SOQPSK-TG
Interferer	Single channel operation
Interference Criteria	1dB change in Eb/No to achieve BER=1e-5
C/I	-20dB,
Telemetry Receiver IF Filtering	SAW filters assumed, no wider than 1.5 times the data rate

Table 2 – ACI Test Conditions

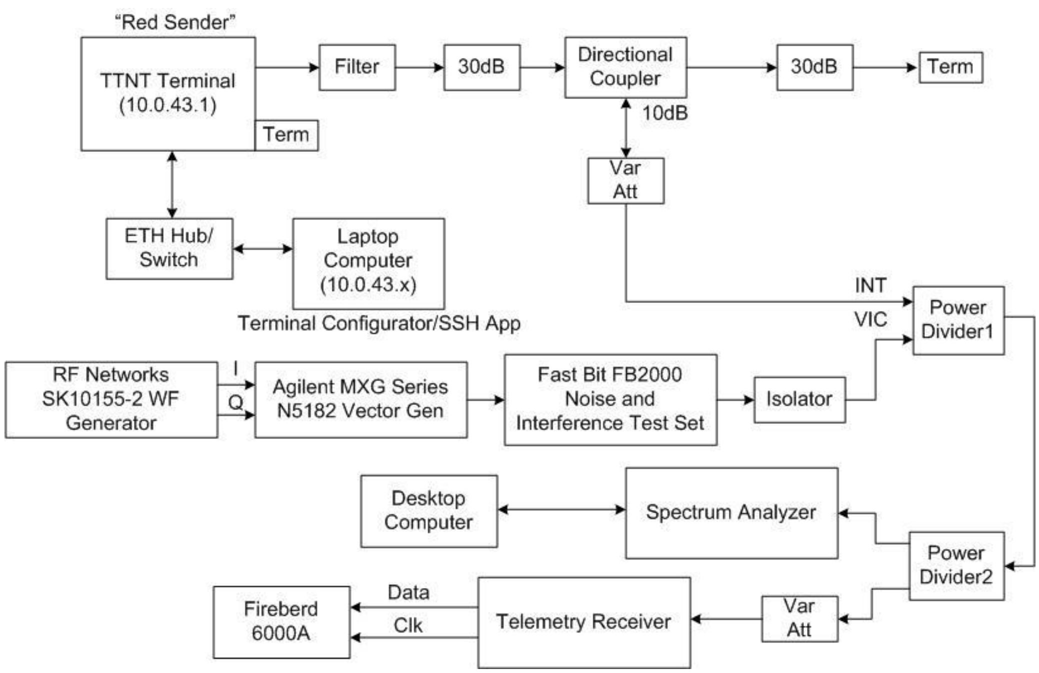

Figure 3 – ACI Testing Block Diagram

The telemetry signal was generated with a pseudo-random bit sequence of length 2^{15}-1 (PRBS15) in either one of two modulation methods, PCM/FM or SOQPSK-TG. For each modulation method tested, utilizing the noise and interference test set (NITS), Eb/No was adjusted to achieve a bit error rate (BER) of $1x10^{-5}$. Starting at a frequency higher than the interferer, the telemetry signal was brought closer to the TTNT signal (interferer) until such a time that a 1dB difference in Eb/No is required to achieve a BER of $1x10^{-5}$. The carrier to carrier spacing was noted and the test repeated with the telemetry signal starting lower in frequency, again noting the minimum spacing.

The keys to performing the ACI testing are setting the correct value for Eb/No and maintaining the proper C/I ratio. Referring to the block diagram, the purpose of the NITS is to set Eb/No of the telemetry signal to a value resulting in a BER of $1x10^{-5}$ for both modulation schemes and all bit rates. For this testing, C/I was set manually due to the burst characteristic of the TTNT waveform. In order to keep the terminal transmitting continuous one-way traffic, a program resident in the terminal ("red sender" program) was utilized. The interferer level was determined by measuring the total power of the TTNT waveform after "Power Divider2" with the telemetry signal off. This determination is accomplished through a method in Appendix A in IRIG-106. For the signals in question, this method gives a good approximation of the unmodulated carrier level typically within 1-2dB. Once this level was determined, the TM signal level was adjusted to give C/I=-20dB. Figure 4 shows a spectrum display of the total power for both signals for C/I=-20dB. In addition Figure 4 shows a spectral capture of one of the ACI test conditions. In this case, the TTNT waveform and the SOQPSK-TG telemetry operating at 5Mbps. The signals are spaced apart by 25MHz.

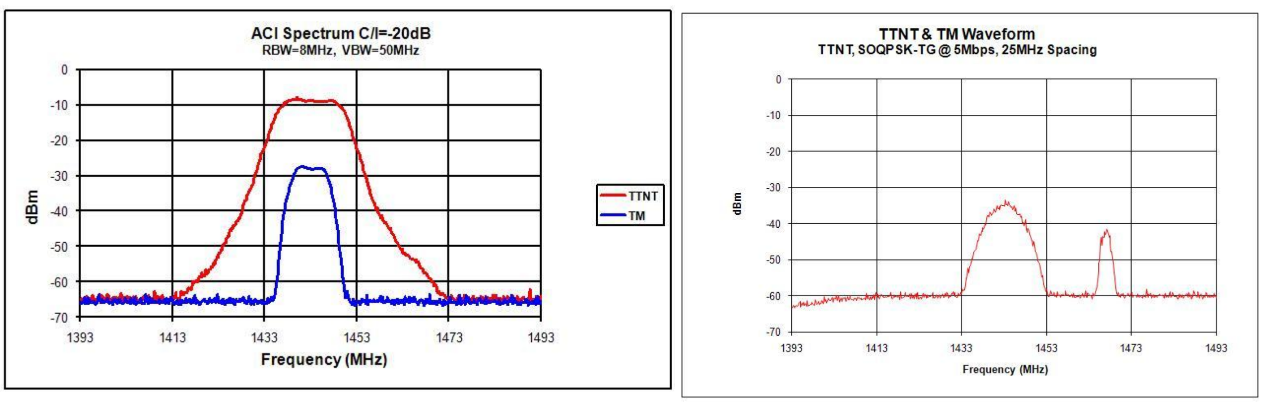

Figure 4 – ACI Total Power Measurement, ACI Spectrum

TESTING RESULTS

ACI testing was done with two telemetry receivers and various TTNT channels, two telemetry modulation modes, and several baseband data rates. Two telemetry receivers were used during the testing in order to get comparative results. The two receivers were a Microdyne RCB2000 and a Semco RC-600A. These are thought to be a representative sampling of receivers used at most of the test Ranges. An effort was made to keep front-end filter selection consistent between receivers, based on data rate and modulation mode, as this selection greatly affects ACI performance. Both receivers implement front-end surface acoustic wave (SAW) filters with similar pass band and roll-off characteristics.

SOQPSK-TG ACI Results

SOQPSK-TG was the first telemetry waveform tested at rates of 5/10/20Mbps. Figure 6 shows results of the 5Mbps testing. This figure shows the relationship between center frequency separation of the TTNT and telemetry signal and the required change in Eb/No to maintain a BER of 1×10^{-5}. To verify that the location of the interferer did not matter, the interferer was placed both higher and lower in frequency than the victim signal and separation numbers were compared.

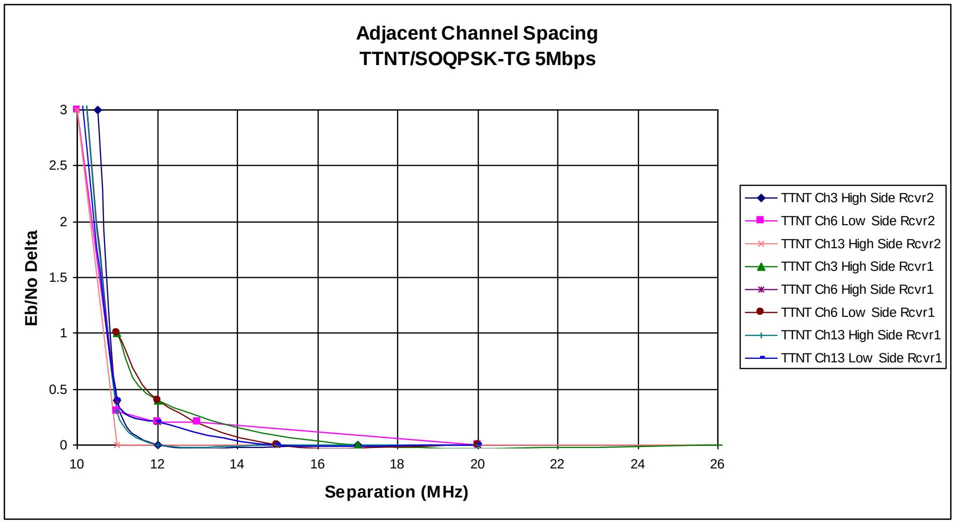

Figure 5 – Separation vs. Delta Eb/No, 5Mbps SOQPSK-TG

Separation data is consistent for each receiver though ACI performance differs slightly. Both high side and low side interference tests were run with receiver #1 and the data shows good correlation with results being symmetric, i.e. it does not matter which side, higher or lower in frequency, the interfering signal is in relation to the victim. The shape of the curves is a characteristic of each receiver. Minimum separation value for this case is on the order of 11MHz.

Next, 10Mbps SOQPSK-TG was used as the victim signal. See Figure 6 for these results. Again, there is some variation in required separation when comparing the two telemetry receivers, but the data for each receiver is well correlated and symmetric (within measurement accuracies) around the victim signal. Minimum separation values range between 13-14MHz for this case.

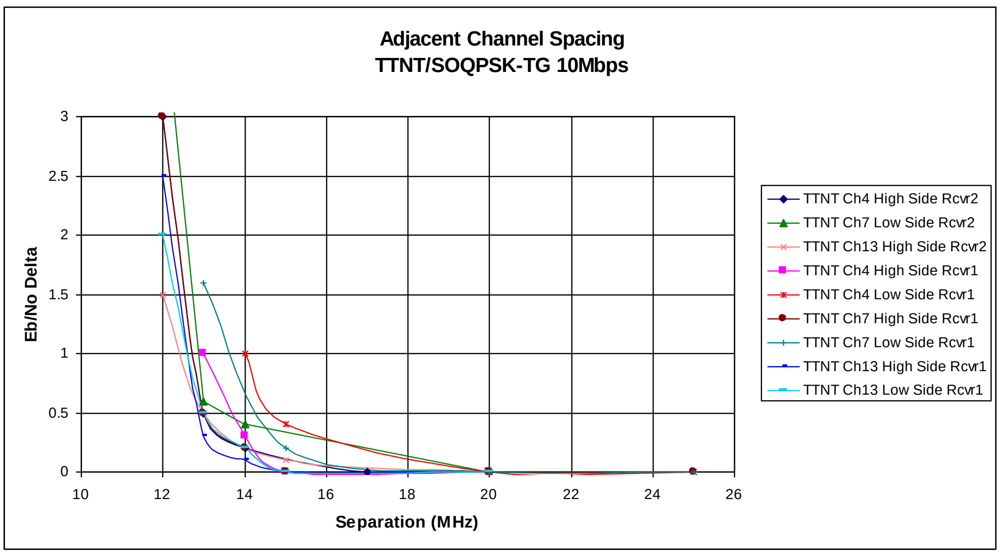

Figure 6 – Signal Separation vs. Delta Eb/No, 10Mbps SOQPSK-TG

The last data rate tested using SOQPSK-TG modulation was 20Mbps. Figure 7 shows data for one telemetry receiver operating at this bit rate. As with the data in Figures 5 & 6, the graph indicates consistency between spacing numbers with a typical value of 17MHz of separation required for this test case.

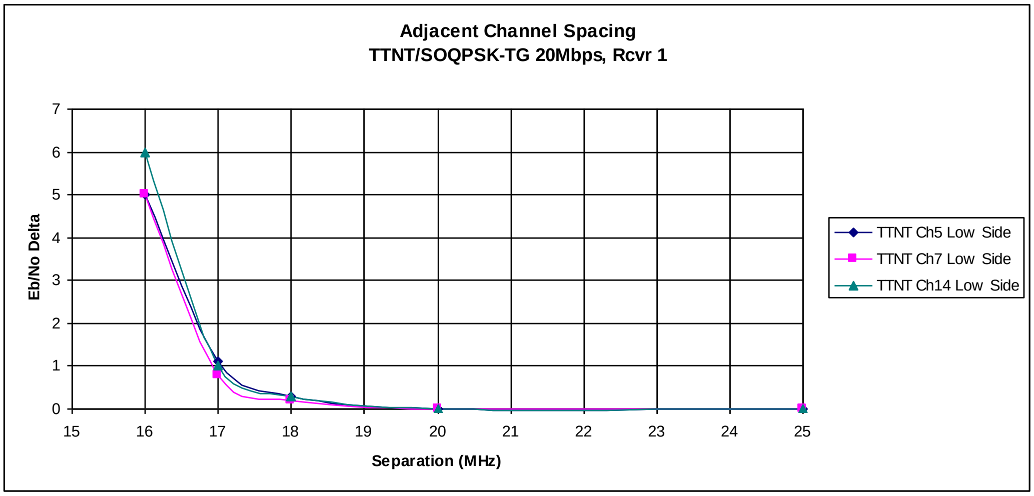

Figure 7 – Signal Separation vs. Delta Eb/No, 20Mbps SOQPSK-TG

Testing with the SOQPSK-TG waveform showed consistent results between telemetry receivers and the results were symmetric around the interfering signal. Refer to Table 3 to see a tabular form of the minimum separation required for each data rate, TTNT channel, and location of carrier signal.

Data Rate	TTNT Channel	Low Side Separation	High Side Separation
5Mbps	CH 3		11MHz
5Mbps	CH 6	11MHz	11MHz
5Mbps	CH 13	11MHz	11MHz
10Mbps	CH 4	13MHz	
10Mbps	CH 7	14MHz	
10Mbps	CH 13	13-14MHz	13-14MHz
20Mbps	CH 5	17MHz	
20Mbps	CH 7	17MHz	
20Mbps	CH 14	17MHz	

Table 3 – SOQPSK-TG Minimum Spacing Variation

As stated above, there is good correlation between high and low side separation values. Given this, the data in Table 3 can be condensed into Table 4.

SOQPSK-TG	Min Freq Separation
5Mbps	11MHz
10Mbps	13MHz
20Mbps	17MHz

Table 4 – Summary of SOQPSK-TG Results

PCM/FM ACI Results

PCM/FM waveform was tested with the interfering TTNT signal at baseband rates of 1 and 5Mbps which are thought to be typical user data rates for this modulation. Again, to verify that the location of the interferer did not matter, the interferer was placed both higher and lower in frequency than the victim signal and separation numbers were compared. The spacing results were found to be symmetric so test data presented is valid regardless of the location of the interfering signal.

For 1Mbps, Figure 8 shows the minimum spacing requirements are between 9-10MHz. There is also good correlation of the data regardless of the TTNT channel selected. Figure 9 shows the results of the testing at 5Mbps, this time with two different telemetry receivers. Correlation of this test data is also good with the resulting minimum separation being 11-12MHz. Testing with the PCM/FM waveform gave consistent spacing results regardless of TTNT channel and location of interfering signal. Refer to Table 5 for a summary of the results.

PCM/FM	Minimum Frequency Separation
1Mbps	10MHz
5Mbps	13MHz
10Mbps	15MHz

Table 5 – Summary of PCM/FM Results

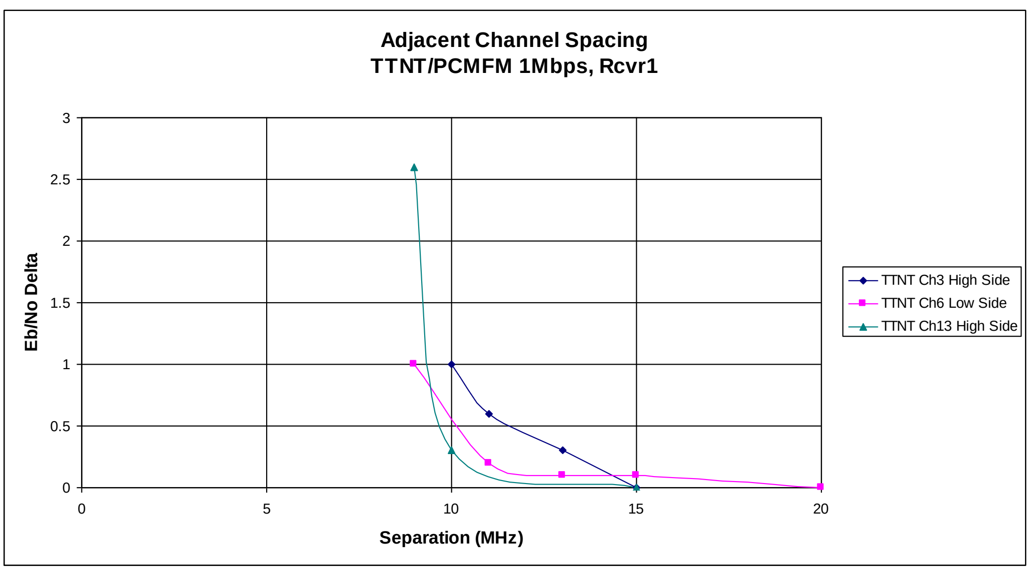

Figure 8 – Signal Separation vs. Delta Eb/No, 1Mbps PCM/FM

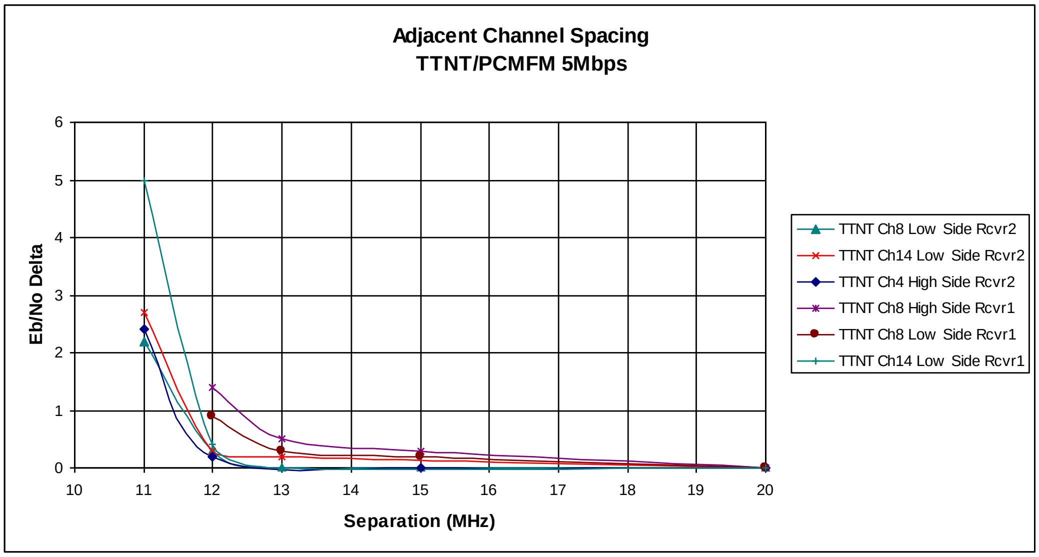

Figure 9 – Signal Separation vs. Delta Eb/No, 5Mbps PCM/FM

MINIMUM SPACING RECOMMENDATION

The Telemetry Standard IRIG-106, Appendix A has a formula for spacing telemetry signals based upon bit rate, modulation mode, and telemetry receiver filter characteristics. This work was accomplished in order to give the Frequency Managers an easy tool that allows them to schedule spectrum more efficiently by knowing exactly how far to minimally space telemetry signals in the AMT bands. Based upon the well correlated data presented for both modulation modes and several representative bit rates, a general equation is presented for calculating the required separation between telemetry and TTNT signals. In this case, the interfering signal is fixed (one of 16 TTNT channels) and the victim signal has two variables, data rate and modulation mode so the minimum frequency separation is a function of the victims user data rate and modulation mode. Note the form of Equation 1 is similar to that in IRIG-106 Appendix A.

$$F_S = R_S * a_S + \Delta f \qquad \text{Equation 1}$$

where:
F_S is the minimum frequency separation (MHz)
R_S is the data rate (Mbps) of the victim signal
a_S is the spacing factor based upon victim modulation type
Δf is the waveform offset (MHz) based upon modulation type

Modulation	**Spacing Factor** (a_S)	**Waveform Offset** (Δf)
PCM/FM	0.5	10
SOQPSK-TG	0.4	9

Table 6 – Coefficients for Minimum Separation Calculation

It should be noted that this is an initial look at minimum spacing requirements for the coexistence of TTNT and telemetry signals in the same frequency band and should not be considered a complete ACI assessment. Single channel operation with a resident program on the terminal was used to excite the channel in order to ease testing and gathering test results. This condition is assumed to be worst case. Further testing may be warranted to assess the impact of the TTNT waveform on telemetry signals when using multiple TTNT channels (i.e. the intended mode of operation), though quantifying these effects will be difficult due to the burst nature of the network traffic and the amount of time the terminals spend on one channel. Also, other telemetry receivers, besides the two tested, should be utilized to investigate their performance and compare those results to the recommended spacing calculation.

CONCLUSIONS

- This is an initial look at minimum spacing requirements for the coexistence of TTNT and telemetry signals in the same AMT band and should not be considered a complete ACI assessment.
- Depending upon the method chosen to determine necessary bandwidth, one channel of a TTNT system can occupy between 14-23MHz of radio frequency spectrum.
- TTNT and telemetry signals can co-exist in the AMT bands with proper spacing.
- Up-front coordination with Test Range Frequency Management is the key to ensuring tolerable interference when TTNT and telemetry signals are to operate in proximity to each other.

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